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Rational Route Choosing Methodology for Machine Parts Restoration and Repair

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Abstract

This paper presents a modern approach to choosing the optimal route for restoration and repair of machine parts with full consideration of their operating parameters as well as economic substantiation for using this or that repair technology.

To determine the optimal restoration route, we need a dependency analysis, for which we should meet the condition that underlies the preventative maintenance system and that is complied with the multiplicity principle.

For thread wear or thread-stripping, there are several methods of thread restoration, such as hole-welding with subsequent threading; mounting a thread insert; hole-machining and oversized threading; use of polymer materials; or mounting a threaded spiral insert. Unlike that, it is far more complicated to choose the optimal route for the worn surfaces restoration. With full consideration of the flux grade and the electrode wire material, there can be as many as 400 or even 500 selectable routes. That is why we can rely on the applicability, durability, and cost-effectiveness analysis to narrow the range of options.

When choosing the best method to correct the defect, one has to duly consider how this part operates, the load it takes, and whether there are fatigue cracks. These data help to select the most optimal route on the applicability basis.

The most accurate and reliable data are obtained on the basis of the real-world use of pairings, nodes, and units.

When finding out whether this or that route is optimal, the techno-economic criterion is the most important one.

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Keywords: parts restoration; parts repair; durability factor; wear resistance factor; adhesion strength; applicability criterion.

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1. Introduction

Choosing the rational route for the restoration and repair of machine parts is a complex problem that requires a careful solution depending on the scale of manufacturing. Generally, optimal routes are chosen based on the analysis of the dependency:

$$\frac{S_m + S_r}{L_r} \le \frac{Sp \cdot C_f}{L_n} \tag{1}$$

where S_m, S_r are the specific quoted expenses for the repair and restoration of parts; L_r, L_n is the service life of repaired and new parts; Sp is the sale price of new parts; C_f is the coefficient that accounts for the transport costs. The condition $\frac{L_r}{L_n} \ge 1$. should hold. [1] This ratio may be referred to as the life recovery coefficient of the part. It should be borne in mind that the value of this coefficient should be in accordance with the multiplicity principle that underlies the preventative maintenance system.

Parts that only require the restoration of worn surfaces are virtually non-existent. However, the problem of choosing the repair route is not very multivariant. [2]

2. Relevance and Problem Statement

Let us consider, for instance, the wear or stripping of mounting bolt thread. The wear of threaded holes is always fairly similar regardless of the material of parts. Such uneven wear is due to the fact that turns of a threaded connection bear an unequal load. There are several practically applicable methods of thread restoration: hole-welding with subsequent threading; installing a thread insert; hole-machining and oversized threading; use of polymer materials; or installing a threaded spiral insert. Unlike that, it is far more complicated to choose the optimal route for the restoration of worn surfaces.

Analysis of the repair methods shows that threaded connections become considerably more durable when repaired with spiral inserts. The problem of choosing the optimal route to restore worn out surfaces is much more complicated. Currently, there are more than 40 coating operations and more than 200 varieties thereof. [3,4]

That is why we propose to rely on the applicability, durability, and cost-effectiveness analysis to narrow the range of options.

The applicability criterion helps choose the best case-specific method to correct the defect. This criterion can be described by the function

$$C_a = f\left(M_p, S_s, D_s, A_w, M_l, \sum T_f\right) \tag{2}$$

where M_p is the material of the part; S_s is the shape of the surface to restore; D_s is the diameter of the surface to restore; A_w is the amount of wear; M_l is the magnitude and nature of the load born by the part; $\sum T_f$ is the total of the technological peculiarities of the route that determine the scope of its optimal use.[6,7,8]

This dependency shows that to choose the restoration route, one had to know how the part or pairing operates, the load it bears, the amount of resulting wear, and whether there are fatigue cracks. To have these data, one needs systematic monitoring and the registration of output. [9,10]

Based on the data presented in Table 1, one can develop restoration routes for worn out surfaces and analyze those routes on the basis of applicability, durability, and the economic criterion.[11,12]

The applicability criterion allows for leaving out the routes that do not meet the part-related requirements.

The durability factor, in general terms:

$$C_d = f\left(C_c, C_e, C_w\right) \tag{3}$$

where C_c is the coating-to-base metal adhesion strength factor; C_e is the endurance ratio; C_w is the wear resistance factor.

Table 1. Technological characteristics of the restoration methods

Technological characteristics of methods	Restoration method codes								
	CO_2	SC	F	EM	Cr	I	ECW	AC	MW
Metals and alloys to which this method is applicable	Steel	Steel, ductile, and gray cast iron	Steel	All materials	Steel	Steel, gray cast iron	Steel, cast iron	All materials	
Surfaces, to which this method is applicable	External cylindrical and flat	External and internal cylindrical	External cylindrical and flat		External and internal cylindrical		External and internal cylindrical as well as flat		
Applicability of the method to parts subjected to alternating loads	Applicable	Not applicable	Applicable	Not applicable	Applicable				
Minimum diameters of parts to which this method is applicable, mm	10	15	35	30	5	12	5	5	10
Minimal inner diameter to which this method applies	-	50	-	-	40	40	50	8	40
Least practical thickness of coating, mm	0.5	0.3	1.5	0.3	0.5	0.1	0.3	0.1	1.0
Maximum practical thickness of coating, mm	3.5	3.0	5.0	8.0	0.6	3.0	1.5	3.0	6.0
Decrease in fatigue strength,%	15	50	15	45	20	25	15	0	30

Meaning of the codes: CO_2 is carbon dioxide welding, SC is short-circuited arc welding, F is flux welding, EM is electrometallization, Cr is chrome plating, I is iron plating, ECW is electrocontact welding, AC is the use of adhesive compositions, and MW is manual welding.

3. Theory, Part Three

According to Prof. A. M. Masino, the adhesive strength is sufficient if it has one of the following values: 500 MPa for external steel surfaces that bear significant impact and alternating loads; 200 MPa for external steel and cast iron surfaces that do not bear a significant impact and alternating loads; 50 MPa for internal mounting surfaces for bearings, which surfaces do not bear alternating and significant impact loads (applies to parts made of steel, cast iron, or aluminum alloys); 40 MPa for external or internal steel or cast iron surfaces that do not bear significant impact or alternating loads on a porous layer, provided that the pairing is well-lubricated. [13,14,15] These values can be assumed as reference values. The value of the adhesion factor can be calculated based on the following dependency

$$C_c = \frac{\tau_c^e}{\tau_c^r} \tag{4}$$

where τ_c^e is the empirical coating-to-base metal adhesion value; τ_c^r is a reference value from the above list, assumed on the basis of operating conditions.[16,17]

Table 2. Life recovery coefficients

Part restoration processes	C_w	C_e	C_a	C_l
1	2	3	4	5
Grinding, iron plating, turning, grinding, hard-alloy burnishing	1.76	1.20	0.8	1.28
Grinding, iron plating, CBN-R turning, and electromechanical strengthening	1.50	1.14	0.8	1.19
Grinding, iron plating, CBN-R turning, grinding, surface plastic deformation	1.23	0.98	0.8	1.06
Electromechanical restoration	1.11	1.42	1.00	1.04
Propane-butane welding, turning, tempering with HFC heating, grinding, surface plastic deformation	1.72	1.06	1.00	1.25
Short-circuit arc welding, hexanit-R turning, grinding, hard-alloy burnishing	1.02	1.22	1.00	1.05
Short-circuit arc welding, hexanit-R turning, grinding, electromechanical strengthening	0.98	1.01	1.00	0.94
Short-circuit arc welding, hexanit-R turning, grinding, surface plastic deformation	0.89	0.94	1.00	0.94
Flux welding, turning, tempering with HFC heating, grinding, hard-alloy burnishing	1.12	1.30	1.00	1.02
Flux welding, turning, grinding, electromechanical strengthening	2.08	1.08	1.00	1.35
Flux welding, turning, tempering with HFC heating, grinding, surface plastic deformation	0.98	1.00	1.00	0.94
Carbon dioxide welding, turning, grinding, electromechanical strengthening	1.80	1.04	1.00	1.28
Carbon dioxide welding, turning, tempering with HFC heating, grinding, surface plastic deformation	0.98	1.00	1.00	0.94
Electrocontact welding, CBN-R turning, grinding, surface plastic deformation	1.08	0.98	0.95	1.00
Electrocontact welding, CBN-R turning, grinding, electromechanical strengthening	1.11	0.98	0.95	1.01
Macnining, flame spraying, tempering with HFC heating, CBN-R turning, grinding	1.10	1.20	0.98	1.1
Macnining, plasma spraying, tempering with HFC heating, CBN-R turning, grinding	1.80	1.60	1.00	1.50
Machining, detonation spraying, CBN-R turning, grinding	2.00	1.00	1.00	1.00
Machining, detonation spraying, grinding	1.80	1.00	1.00	1.00
Machining, polymer composition coating, machining	1.20	1.20	0.95	1.10
Manual welding, CBN-R turning, grinding, surface plastic deformation	0.82	0.80	1.00	0.75
Manual welding, turning, tempering with HFC heating, grinding, surface plastic deformation	0.93	0.90	1.00	0.83

The endurance ratio is the ratio of the endurance limit of the coating $\left(\sigma_B^B\right)$ (applied and machined according to a specific restoration route) to the endurance limit of the new part $\left(\sigma_B^H\right)$

$$C_e = \frac{\sigma_B^B}{\sigma_B^H} \tag{5}$$

This ratio is determined on the basis of laboratory and bench testing. Table 2 presents the results of fatigue strength tests carried out on a RUMI−30 machine under conditions close to the load for most parts of forestry machines.

The wear resistance factor can be estimated on the basis of laboratory tests using a SMC−2M friction machine. The wear resistance factor C_w is calculated per the formula:

$$C_w = \frac{C_s^{\mathrm{res}}}{C_s^{\mathrm{ref}}} \tag{6}$$

where C_s^{res} is the wear resistance of the restored surface; C_s^{ref} is the wear resistance of the reference surface.[18]

Table 2 presents the test results obtained under the following conditions: slip velocity of 0.25 m/s, a load of 784 MPa, and a 4700 m slip distance (after breaking-in).

The durability factor can be determined by different methods. Prof. M.A. Mashino [3] proposes to use the least values of its three constituent factors. Table 2 provides an example [1].

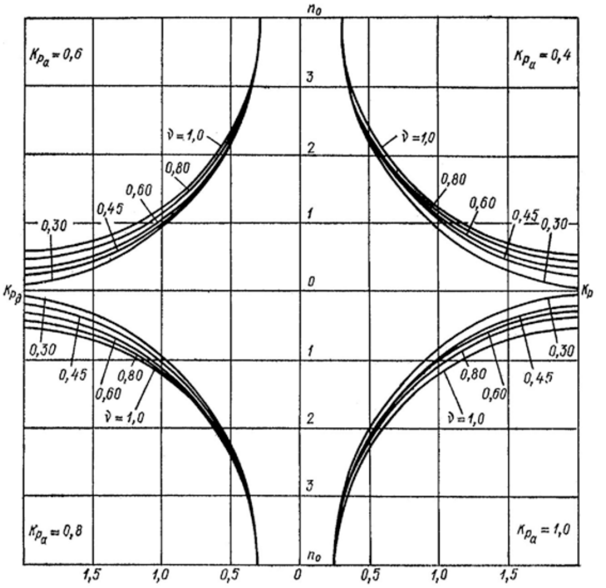

Fig.1. Nomogram for determining the number of failures of a part in a unit over the post-repair service life.

ν is the variation coefficient of the part; C_{ru} is the unit life coefficient; C_{rd} is the life coefficient of the restored part.

Other scientists and researchers [2] propose calculating the durability factor as a product of its constituent factors. We believe that the durability factor can be calculated as follows

$$C_d = rC_wK_b^m \tag{7}$$

where r is the basic variable; m is the tilt of the left branch of the fatigue curve per GOST 25.504−82 (m=1.96) provided that $C_c \geq 1$. [19]

The techno-economic criterion is the most important one, as it is this criterion that determines whether this or that restoration route is optimal or not. The technical aspect of this criterion is defined by the reliability of the restoration and repair process:

$$\frac{S_m + S_r + S_c}{L_r} \leq \frac{Sp \cdot C_f}{L_n} \tag{8}$$

where S_c are the specific quoted costs related to the elimination of the consequences of failures, see GOST 23.1.47–80,

$$S_c = \frac{S_q \cdot n_O}{T_P(n-1)} \tag{9}$$

where S_q are the specific quoted costs of repairing a unit in which there is a repaired and restored part; n_o is the probable number of failures related to the restored part, expected in the post-repair service life; n is the number of repaired and restored parts in the unit; S_p is the price of a new or a spare part; C_f is the transport costs factor; T_p is the service life of a repaired and restored part.[20]

4. Conclusion

For the main units of tracked vehicles that have not been overhauled, the variation coefficient is 0.3...0.4; for those that have been overhauled, the value is 0.6...0.8.

If $K_p \geq 1$, then the costs of eliminating the consequences of a failure are not accounted. If the left part, see Figure 1, exceeds the right part, then one had better purchase spare parts and not repair or restore the broken part, because such repair and restoration would not be cost-effective.

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